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(54) **FREE PISTON ENGINE**

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EP 3 137 754 B1

Description**FIELD OF THE INVENTION**

5 **[0001]** The present invention relates to the field of internal combustion engines, and more particularly to the field of internal combustion engines having a free end piston.

BACKGROUND OF THE INVENTION

10 **[0002]** Internal combustion engines are known. The most common types of piston engines are two-stroke engines and four-stroke engines. These types of engines consist a relatively large number of parts, and require a numerous number of auxiliary systems, e.g., oiling, cooling and the like, for proper functioning.

15 **[0003]** GB2183726(A) discloses a double-action two-stroke internal combustion engine. The engine is provided with an exhaust valve that moves on and with respect to the piston rod and does not form an integral portion thereof. The exhaust valve is rearwardly tensioned by a spring and opens by a tenon when the piston moves to the other side. The exhaust takes place when the piston reaches the other side, and the exhaust valve closes as soon as the piston starts moving to the other side.

20 **[0004]** The disadvantages of '726 are: the need to produce the exhaust valve slidably matching to the piston rod, the necessity to provide a spring and a mechanical opening mechanism to the valve, and, the inefficient gas exchange process.

25 **[0005]** US5676097(A) discloses a high-efficiency internal combustion engine provided with a double-acting piston cooperating with auxiliary feed inlet units. The exhaust opening is located at the center of the cylinder, and the inlet openings are located at the edges of the cylinder and use a valve (19).

30 **[0006]** US2012280513(A1) discloses a free piston engine. The engine is very long. A piston, located at each side of the engine is connected by means of an internal rod to the other piston. The engine contains liquid therein and the exhaust is carried out by means of a mechanical valve located at each side of the engine. The mechanical power is not received outside the engine but within the engine.

35 **[0007]** The '513 application suffers from the disadvantage that it requires a dedicated exhaust valve and a mechanism for operation thereof.

40 **[0008]** US4831972(A) discloses an internal combustion engine having the spark plugs located at a center thereof. The mechanical power received by the engine remains within the engine.

45 **[0009]** US6722322(B2) discloses an internal combustion engine comprising two pistons that form a kind of an engine head. An external spring serves to hold an internal plunger.

50 **[0010]** DE102008004879(A1) discloses a free piston engine, for example, for an excavator, that has a heat engine with free pistons, linear generator driven by the heat engine for generating electrical energy, and pump assembly driven by the heat engine for generating hydraulic and/or pneumatic energy.

55 **[0011]** US6199519(B1) discloses a free piston engine which is self-ignited without the need of spark plugs. No power is going out from the engine and the inlet and exhaust are provided at both sides of the cylinder side.

60 **[0012]** US4385597(A) discloses a two-stroke internal combustion engine having three pistons; one central piston and two side pistons moving with respect to the central piston.

65 **[0013]** US4414927(A) discloses a two-stroke oscillating piston engine having three pistons. Neither of the piston rods serve as an exhaust valve.

70 **[0014]** JPS63192916(A) discloses a linear engine having three pistons.

75 **[0015]** GB2353562(A) discloses an internal combustion engine with a rigid piston / connecting rod unit and two combustion chambers, also with thermal insulation and water spray into the combustion chambers. A disadvantage of the engine of '562 is that it requires inlet and exhaust valves at each side of the engine.

80 **[0016]** US5351659(A) discloses a shaft engine including a piston, which moves in a cylinder to reciprocate at least one cylinder shaft causing it to turn a crank shaft. The at least one cylinder shaft has a respective longitudinal air passage for sending exhaust gas out of the cylinder, the air passage being linked to a raised air chamber on the cylinder through a respective extension tube.

85 **[0017]** DE202006018097(U1) discloses a free-piston engine that is connected to a pre-compressor and a turbine. The free-piston engine has at least one piston that can be reciprocated in a cylinder compartment and divides the same up into two combustion chambers, the pre-compressor being operable electrically and/or assisted by exhaust gas.

90 **[0018]** It is the object of the present invention to provide a free piston engine that significantly reduces or overcomes the aforementioned disadvantages.

95 **[0019]** It is a major object of the present invention to provide a new method of gas exchange in an internal combustion engine.

100 **[0020]** It is a further major object of the present invention to provide a free piston engine that enables constant flow

of pre-charged fresh air into and through the cylinder and through the piston rod regardless the position of the piston, and, through the exhaust system, irrespective of the combustion action taken at a given time.

[0021] It is a further object of the present invention to provide a new cycle process in an internal combustion engine which differs from an Auto cycle, Atkinson cycle, or two stroke cycle.

[0022] It is still another object of the present invention to provide a multifunctional piston.

[0023] It is yet another object of the present invention to provide a piston that functions as an inlet valve, and, a piston rod that functions as an exhaust tube and as an exhaust valve.

[0024] It is still a further object of the present invention to provide a free piston engine embodying direct low-pressure fuel injection.

[0025] It is yet another object of the present invention to provide a free piston engine embodying a traverse stressless action piston.

[0026] It is a further object of the present invention to provide a free piston engine which prevents compressed gas leakage by diverting the flow of gases to a longer path and reducing the convergence of gases toward the gap between the engine head and the piston rod.

[0027] It is still a further object of the present invention to provide a free piston engine having a piston rotation prevention mechanism. It is still yet another object of the present invention to provide a free piston engine having a split sealing ring rotation prevention system.

[0028] It is also another object of the present invention to provide a free piston engine having electric generators at its perimeter.

[0029] It is still another object of the present invention to provide a free piston engine that transforms linear movement to rotational movement.

[0030] It is yet another object of the present invention to provide a low cost free piston engine.

[0031] It is a further object of the present invention to provide a new internal combustion engine that is efficient, have a small number of parts, have a high power to weight ratio, and significantly reduces air pollution and fuel consumption.

SUMMARY OF THE INVENTION

[0032] A known auto cycle process comprises the following steps: Intake - Compression - Work - Exhaust. A known two-stroke cycle process comprises the following steps: Work & compression - exhaust & intake along the piston move from a top point of the cylinder to the bottom point of the cylinder and up again (complete cycle).

[0033] The cycle process of the present invention, which may be called an "Aquarius cycle", comprises the following steps: Work - exhaust - scavenging - gas boost - compression - work. The present invention suggests this new cycle and the present design allows it to take place symmetrically and simultaneously (i.e., when a given first side of the cylinder goes under a given step of the cycle, the opposite side of the cylinder goes also under a step of the cycle, however, under a different step comparing to the step occurring at the first side of the cylinder) inside the cylinder on both sides of the cylinder. The entire cycle takes place inside the cylinder every time the piston completes its stroke from one end of the cylinder to the other end and simultaneously.

[0034] A continuous flow of pre-charged air through the cylinder serves, beside of being used for combustion, also for burned gas scavenging, for cooling the cylinder wall and the piston, and for enriching the burned gases of the exhaust chamber.

[0035] In accordance with the present invention there is provided an internal combustion engine, as recited in claim 1, for generating a linear reciprocating movement of an output shaft along a longitudinal axis.

[0036] Innovatively, the engine operates through an Aquarius cycle, the Aquarius cycle comprising the steps of: (a) work, (b) exhaust, (c) scavenging, (d) gas boost, (e) compression. Preferably, the exhaust openings are arranged in at least one group. Typically, the exhaust openings are arranged in a multitude of groups.

[0037] If desired, the cylinder comprises inlet openings at a central portion thereof.

[0038] Practically, the cylinder comprises a continuous flow of pre-charged air therethrough.

[0039] Advantageously, the cylinder comprises a cylinder wall at an inner portion thereof, and, the continuous flow of air scavenges the cylinder from burned gases, cools the cylinder wall and the piston, and enriches the burned gases without depending on the position of the piston.

[0040] Innovatively, the burned gases exhaust the cylinder through the piston rod.

[0041] Advantageously, the burned gases exit the cylinder at the end of an efficient work stroke.

[0042] Typically, the piston constitutes a multifunctional piston.

[0043] Advantageously, the piston constitutes a traverse stressless action piston.

[0044] If desired, the engine comprises a transient chamber connected to the exhaust manifold for prevention of burned gas leakage.

[0045] Typically, the engine comprises sealing rings for sealing between the piston rod and the engine head and between the piston rod and the exhaust unit, and wherein:

the sealing rings are stationary and the piston rod slides therein and with respect thereto.

[0046] Further typically, the sealing rings comprise split rings that tend to close inwardly against the piston rod.

[0047] In some embodiments, the engine comprises intake openings and the exhaust openings are near the intake openings.

5 [0048] If desired, the engine comprises an aligner system for preventing rotation of the piston around the longitudinal axis.

[0049] Practically, the aligner system comprises aligner rods that are directed parallel to the longitudinal axis and are connected to the piston rod through connecting arms.

10 [0050] Advantageously, the aligner rods comprise coil windings, and the engine comprises an electric motor that generates electric power by means of stator coils that are energized by a linear back and forth movement of the aligner rods therethrough.

[0051] Typically, the engine comprises an imaginary peripheral envelope which is around and distanced away from the longitudinal axis; and the stator coils of the electric motor are positioned around the peripheral envelope and distanced from the longitudinal axis.

15 [0052] Further advantageously, the engine comprises a system for transforming linear movement to rotational movement.

[0053] In some embodiments, the system comprises:

20 a first pinion rotated by a first rack that is connected to a first aligner rod, the first pinion is rotated to a single direction; a second pinion rotated by a second rack that is connected to a second aligner rod that is adjacent the first aligner rod, the second pinion is rotated to a single direction that is the same as the rotation direction of the first pinion; and the first pinion and the second pinion are aligned and rotate around an output axis.

BRIEF DESCRIPTION OF THE DRAWINGS

25 [0054] For a better understanding of the present invention and to show how the same may be carried out in practice, reference will now be made to the accompanying drawings, in which:

30 Fig. 1 is a perspective view of a free piston engine according to the present invention;
 Fig. 2 is a side cross-sectional view of the engine of Fig. 1, according to a first embodiment;
 Fig. 3 is a perspective exploded view of the engine of Fig. 1;
 Fig. 4 is a perspective view of the cylinder of the engine of Fig. 1;
 Fig. 5 is a top perspective view of the cylinder of Fig. 4;
 Fig. 6 is a perspective view of the piston and piston rods of the engine of Fig. 1;
 35 Fig. 7 is a perspective view of an exhaust unit of the engine of Fig. 1;
 Fig. 8 is a perspective view of a modified version of the engine head when valves are used;
 Fig. 9 is a perspective view of an upper portion of the intake manifold of the engine of Fig. 1;
 Fig. 10 is a perspective view of a lower portion of the intake manifold of the engine of Fig. 1;
 Fig. 11 is a cross-sectional side view of another embodiment of a free piston engine according to the present invention;
 40 Fig. 12 is a perspective exploded view of the engine of Fig. 11;
 Fig. 13 is a perspective view of the cylinder of the engine of Fig. 11;
 Fig. 14 is a perspective view of the engine head of the engine of Fig. 11;
 Fig. 15 is a perspective view of the piston and piston rods of the engine of Fig. 11;
 Fig. 16 is a perspective view of the piston alignment system of the engine of Fig. 11;
 45 Fig. 17 is a perspective view of another embodiment of a free piston engine according to the present invention showing the connection of electricity generating unit to the engine;
 Fig. 18 is a perspective view of another embodiment of a free piston engine according to the present invention equipped with a mechanism for transforming linear movement to rotational movement;
 Fig. 19 is a perspective view of another embodiment of a piston rod according to the present invention;
 50 Fig. 20 is a schematical cross-sectional view of a free piston engine according to the present invention during a first step of an Aquarius cycle;
 Fig. 21 is a schematical cross-sectional view of a free piston engine according to the present invention during a second step of an Aquarius cycle;
 Fig. 22 is a schematical cross-sectional view of a free piston engine according to the present invention during a third step of an Aquarius cycle; and
 55 Fig. 23 is a schematical cross-sectional view of a free piston engine according to the present invention during a fourth step of an Aquarius cycle.

DESCRIPTION OF PREFERRED EMBODIMENTS

[0055] Attention is first drawn to Figs. 1 to 10 that show a free piston engine **10** according to the present invention. The free piston engine **10**, having a longitudinal axis **A**, is an internal combustion engine. For a matter of simplicity, the free piston engine **10** will hereinafter be called "engine".

[0056] The engine **10** comprises a two-sided cylinder **12** having a plurality of peripherally distributed inlet openings **14** in a central portion **16** of the cylinder **12**. Typically, the inlet openings **14** are evenly distributed around the periphery of the cylinder **12**. The inlet openings **14** are peripherally bounded by an intake manifold **18**. The intake manifold **18** comprises an intake manifold upper portion **20** that is connected to an intake manifold lower portion **22**. The intake manifold upper portion **20** comprises, at an upper portion thereof, an air intake **24** through which pre-charged fresh air gets into the cylinder **12**. Each side of the cylinder **12** is closed by an engine head **26** and is provided with a plurality of spaced-apart disc-like cooling fins **28**. In some cases, according to design needs, the engine **10** may be cooled by using coolant of a type known in the art.

[0057] It should be noted that directional terms appearing throughout the specification and claims, e.g. "forward", "rear", "upper", "lower" etc., are used as terms of convenience to distinguish the location of various surfaces relative to each other. These terms are defined with reference to the figures, however, they are used for illustrative purposes only, and are not intended to limit the scope of the appended claims.

[0058] A piston **30** is located within a cylinder inner space **32** of the cylinder **12** and can freely slide back and forth along the cylinder inner space **32**, in the direction of the longitudinal axis **A**. The piston **30** is double-sided, solid, and symmetrical with respect to a median plane **P** thereof.

[0059] A piston rod **34** is connected to each side of the piston **30**, at a center thereof, symmetrically with respect to the longitudinal axis **A**. Each of the two piston rods **34** is hollow, i.e., comprises a longitudinally extending cavity **36** that extends along the entire length of the piston rod **34**. Since the piston **30** is solid, as was mentioned above, it should be clear that the cavity **36** of a given piston rod **34** is not connected to the cavity **36** of the other piston rod **34**, and no gas can flow through the piston **30** from one side thereof to the other side thereof.

[0060] Each piston rod **34**, comprising an integral part of a "sliding valve" (as will be later described) and of the multi-functional piston, is provided with a plurality of exhaust openings **38**. According to a specific embodiment of the present invention, the exhaust openings **38** of each piston rod **34** are arranged in three groups, namely, an inward group **40**, which is closest to the piston **30**, an outward group **42**, which is farthest from the piston **30**, and, a central group **44**, which is located between the inward group **40** and the outward group **42**.

[0061] The distance between the exhaust openings groups and their location with respect to the piston, or, if desired, the number of groups are determined according to design needs. Each group, i.e., the inward group **40**, the outward group **42** and the central group **44** are provided with a plurality of exhaust openings **38**. The exhaust openings **38** of each group are equally distanced from the piston **30**. Furthermore, according to a specific embodiment of the present invention, the exhaust openings **38** of a given group are equally peripherally distributed around the piston rod **34**.

[0062] The distance of the exhaust openings **38** of the inward group **40** from the piston **30**, measured from the nearest point of the exhaust openings **38** to the piston **30**, determines the compression ratio of the engine **10**.

[0063] Each of the engine heads **26** comprises a region for allocating therein a spark plug and a fuel atomizer **45**. Alternatively, the fuel atomizer **45** may be applied at the central portion **16** of the cylinder or at a cylinder wall **33**.

[0064] The distal end of each of the engine heads **26** is closed by an exhaust unit **48**. The exhaust unit **48** is connected to each of the engine heads **26**, or, can be combined with or be an integral part of each of the engine heads **26**. Each exhaust unit **48** comprises an exhaust chamber **50**, at an inner portion thereof, and, exhaust cooling fins **52**, at an outer portion thereof. An upper portion of each of the exhausts **48** comprises an exhaust outlet **54**.

[0065] A general description of the engine operation will now be described. When the piston **30** slides within the cylinder inner space **32** it closes and exposes, correspondingly, the inlet openings **14** through which enters the pre-charged air required for the entire engine operation, i.e., combustion, cooling, scavenging, and, oxidation of burned gases. According to preferred embodiments of the present invention, the air which enters the cylinder is pre-charged (by a system that is not shown). When the piston rods **34** move, they expose and close, correspondingly, to the exhaust chamber **50**. In this position, the exhaust gases may flow out from the exhaust chamber **50** to the exhaust outlet **54**. If it is required, the exhaust gases may further flow into a turbo-charging system (not shown).

[0066] When the piston **30** moves from the central portion **16** of the cylinder **12** towards an engine head **26**, the inlet openings **14** and the exhaust openings **38** are closed, and a compression stroke takes place (see Fig. 23, when the piston moves to the right side). Fuel is injected into the cylinder inner space **32**, through an atomizer **45** (see Fig. 11), and is ignited by means of a spark plug **46** (see Fig. 20). The ignition of the fuel and air mixture creates a combustion that is known as a power stroke or work stroke (see Fig. 21).

[0067] It should be noted that the engine of the present invention utilizes a single center atomizer, instead of several atomizers used in conventional engines. Alternatively, the engine may use two atomizers, one on each engine head or near the top end of the cylinder wall **33**.

[0068] In addition, fuel is injected through the atomizer in the beginning of the compression stroke, wherein, generally, in prior art engines, fuel is injected into a combustion chamber only at the end of the compression stroke. This feature enables the engine of the present invention to perform a "direct low pressure injection", i.e., enables to inject the fuel, into a chamber consisting air, at about 3 bar, instead of injecting the fuel, into a chamber consisting air, at about 100 bar or more. This direct low pressure injection, in contrary to the commonly used high pressure injection, encounters various advantages as can be appreciated by a person skilled in the art. For example, (1) safety - using low pressure considerably reduces the chance of a leak, (2) energy saving due to the need to inject the fuel at lower pressure, (3) better atomization of the air and fuel, leads to better combustion and lower fuel consumption, and, hence, reduced air pollution.

[0069] Now, during the work stroke, the piston **30** moves toward the opposite side of the cylinder **12** and moving therewith the piston rods **34**. During the movement of the piston rods **34** (to the right side as seen in Fig. 21), the exhaust openings **38** (which are behind the piston, i.e., the exhaust openings which are on the left of the piston) are exposed to the cylinder inner space **32** and enable the burned gases to flow through the piston rod **34** toward the exhaust chamber **50** and to the exhaust outlet **54** (see the change from Fig. 21 to Fig. 22).

[0070] This unique and special action allows the burned gases to be discharged immediately after ending the efficient work stroke. The efficient work stroke is defined as the difference between the high pressure after the combustion, leading to an effective stroke (movement of the piston) and thereafter increase of the cylinder's free space causing to reduced pressure at that space, at which point the gas pressure is no longer effective but has transited to a kinetic force moving the piston. Thus, due to a relatively short time of presence of burned gases within the cylinder **12**, the cylinder is kept relatively cold and the exhaust unit **48** hot.

[0071] During the continuation of the movement of the piston **30** the inlet openings **14** are exposed and pre-charged fresh air gets, through the air intake **24**, to the cylinder inner space **32** that has just gone through a work stroke (see Fig. 23). The pre-charged air scavenges the cylinder's inner space **32** from any residues of burned gases, cools the cylinder from the inside and enriches the burned gases at the exhaust unit with fresh air so that any residues of un-burned fuel are burned. Another important issue is that as the piston **30** keeps moving toward the other end of the cylinder **12**, the pre-charged air fills the growing size of the cylinder's free space, thus eliminating suction of the burned gases back into the cylinder.

[0072] Simultaneously, the air that was in the opposite side of the piston **30** is first boosted until the exhaust valve openings are closed, and then compressed, thus starting another compression stroke at the other side. The action of the exhaust openings that open, intermittently, to the cylinder inner space **32**, and, to the exhaust chamber **50**, and, also allows burned gases to flow from the cylinder inner space **32** to the exhaust chamber **50**, may be defined as a "sliding valve" action.

[0073] It should be noted that when the piston **30** reaches its maximal stroke to the left (see Fig. 2) within the cylinder inner space **32**, all the exhaust openings **38** of the left piston rod **34**, i.e., the exhaust openings of the inward group **40**, of the central group **44** and of the outward group **42**, are located within the left exhaust chamber **50** and no exhaust openings **38** of the outward group **42** are exposed to the atmosphere at any case. In this position, the exhaust openings **38** of the outward group **42** of the other piston rod **34**, i.e., the right piston rod **34**, are positioned within the right exhaust chamber **50**, while the exhaust openings **38** of the inward group **40** and of the central group **44** of the right piston rod **34** are positioned within the cylinder inner space **32**.

[0074] Attention is now drawn to another embodiment of the present invention, shown in Figs. 11-12, 15-16. As shown, the piston rod **34** is provided, instead of the round exhaust openings, with longitudinally extending exhaust slots **56**. In the embodiment shown, the piston rod **34** is provided with four sets **58** of exhaust slots **56** at each side of the piston **30**. In each set **58** of exhaust slots **56**, each of the exhaust slots **56** is symmetrically arranged with respect to the longitudinal axis **A** and with respect to the exhaust slots **56** at the other side of the median plane **P**.

[0075] According to other embodiments of the present invention (not shown in the figures), a similar action of a "sliding valve" for the exhaust gases may be achieved by using a piston rod having different diameters along the length thereof. Thus, the piston rod has a full size diameter adjacent the piston and at the exhaust unit external end, and, a smaller diameter inbetween. With this construction, the exhaust gases can freely flow from the cylinder inner space **32** to the exhaust chamber **50** as the piston slides from one end to the other.

[0076] Furthermore, the piston rods **34** are connected to an aligner system **60** (see Fig. 16) for preventing rotation of the piston rods **34** around the longitudinal axis **A**, thus featuring an "aligned movement piston". Each of the piston rods **34** is connected, at a free end **62** thereof distal from the piston **30**, to a connecting arm **64**. The connection of the connecting arm **64** to the piston rod **34** is such that the connecting arm **64** cannot rotate with respect to the piston rod **34** around the longitudinal axis **A**. This is done, e.g., by threadingly engaging between the piston rod **34** and the connecting arm **64**, or, by forming the free end **62** of the piston rod **34** as a protrusion with a non-round form, and, assembling thereon the connecting arm **64** having a corresponding non-round indentation. A securing bolt **66** securely attaches the connecting arm **64** to the corresponding piston rod **34**.

[0077] An aligner rod **68**, having a cylindrical shape and an aligner rod axis **B**, is perpendicularly connected at each

end of the connecting arms **64**. The aligner rods **68** are inwardly connected with respect to the engine **10**, and are directed such that the aligner rod axis **B** is parallel to the longitudinal axis **A**.

[0078] As shown in Fig. 11, each exhaust unit **48** is provided, outside of the exhaust chamber **50** thereof, with aligning bores **69** that correspond to the aligner rods **68** in size and location. Thus, when the engine **10** is assembled and each of the aligning rods **68** freely slides within its corresponding aligning bore **69**, it is guaranteed that the piston **30** together with the piston rods **34** will move back and forth only along the longitudinal axis **A**, while rotation of the piston **30** and the piston rods **34** around the longitudinal axis **A** is successfully prevented.

[0079] In order to prevent gases from passing between the piston rod **34** and exhaust unit outer end to the atmosphere as well as sealing against leakage of gases between the piston rod **34** and the engine head **26** and also to prevent gases from passing from one side of the piston **30** within the cylinder inner space **32** to another side of the piston **30** within the cylinder inner space **32**, the engine **30** is provided with sealing rings **70**.

[0080] The sealing rings **70** at both ends of an exhaust unit **48** have a similar construction. Each sealing ring **70**, resting within a sealing ring housing **72** formed in the exhaust unit **48**, comprises two exhaust rings **74** having a ring spacer **76** therebetween. The exhaust rings **74** are split rings and are formed such that they tend to squeeze inwardly in order to seal the gap between the exhaust ring **74** and the piston rod **34**. The sealing rings **70** are stationary wherein the piston rods **34** slide therein.

[0081] A securing pin **78**, connected to an exhaust cover **80**, is directed to the gap formed between two edges of the split ring, thereby preventing the split ring, i.e., the exhaust ring **74**, to rotate around the longitudinal axis **A** with respect to the piston rod **34**. The exhaust ring **74** may be located at the end of the engine head **26** as described above and does not necessarily be installed at the exhaust chamber **50**.

[0082] Thus, by the aligner system **60** and the securing pins **78** it is assured that any relative rotational movement between the piston rods **34** and the split rings (i.e., the exhaust rings **74**) is prevented, thus assuring unlimited free slide of the piston rods **34** relative to the sealing rings **70** without any risk that the exhaust slots **56** of the piston rods **34** may hit the gap between the split rings. When assembling the system, care must be taken to assure that the sealing rings **70** are stationary and that the piston rods **34** can freely slide through the sealing rings **70**.

[0083] The sealing rings of the piston **30** have a similar construction to the described above with the difference that the split rings tend to extend outwardly, opposite to the described above, thus assuring that the sealing ring forcibly presses against the cylinder wall **33**, thus assuring appropriate sealing of the piston **30** against the cylinder wall **33**.

[0084] In order to ensure better sealing between the piston rod **34** and the engine head **26** at the exiting hole from the engine head **26**, a special design is applied. According to the design, the compressed gases are forced to return into the cylinder inner space **32** instead of squeezing into the gap between the piston rod **34** and the engine head **26**. The special design moves the clearance gap between the head port and the piston rod **34** from the apex of the parabola at the engine head combustion chamber to a lower point closer the cylinder top end. At the compression stroke the gases are forced to change direction backwards and not to be squeezed into the gap between the head port and the piston rod **34** and leak out.

[0085] Fig. 17 shows another embodiment of the engine **10** according to the present invention. As shown in Fig. 17, each of the connecting arms **64** has an X-shape, thus having four connecting arm edges **82**. According to some embodiments, the four connecting arm edges **82** are connected therebetween, thus forming a generally square shape that encircles the X-shape connecting arms. The aligner rods **68** run along the entire length of the engine **10** and are connected, at both ends thereof, to the connecting arm edges **82**.

[0086] Each of the aligner rods **68** is provided with a rotor assembly and coil windings **84** that form in practice a rotor **86** of an electric motor **88**. Such a rotor **86** moves back and forth in a linear motion together with the connecting arms **64** that are connected to the piston rods **34** similar to a linear motor as known in the art.

[0087] Stator coils **90**, connected to stator support brackets **92** that are located along and around the engine **10**, are formed around each of the rotors **86**. As shown, the electric motor **88** is formed around the engine **10**, thus forming an efficient and compact structure. Furthermore, the stator coils **90** are arranged in a way that forms a new and unique "magnetic polarity array" of an electricity producing device.

[0088] According to the explained above, the engine according to the present invention is a linear, free piston, internal combustion engine that serves as a driving force to a power generator, by converting chemical energy stored in fuel to a useful mechanical energy. The engine can be applied to electrical propulsion, electrical accumulators, and other electrical consuming applications, or can be used to compress air or propel a propeller.

[0089] In order to show the advantages of the engine according to the present invention, a comparison is made with relation to a conventional four-cylinder engine.

<u>Prior Art</u>	<u>Present Invention</u>
Power - about 80hp	Power - estimated 80hp

(continued)

Prior Art	Present Invention
Total weight - average 70 kg	Total weight - about 14 Kg
Volume - average 1300cc	Volume about 750cc
Air pollution - within standards	Air pollution - minimal, measured value threshold
Complicated engine block	Simple engine block
Complicated engine head	Two engine heads (covers)
Four pistons	One double sided piston
Four piston rods	Two piston rods
Four atomizers	One or two atomizers

[0090] Furthermore, the following part list, which exists in a conventional engine, is omitted from the engine according to the present invention:

Crank shaft, crank shaft bearings, crank shaft oil retainers, oil retainers housing for connecting rods bushings, connecting rods bearings, oil pump, lubrication system, oil sump, water pump, cam shaft, timing system, valves, valves guides, valves sealings, rockers, valves covering, counter shaft, upper oil retainers and sealings.

[0091] As can be seen from the above list and table, the engine of the present invention provides considerable advantages with respect to prior art engines, e.g., reduced number of parts, reduced weight, reduced air pollution, improved power to weight ratio, simple maintenance, improved mechanical reliability, reduced volume, and does not require internal oiling system.

[0092] Furthermore, since the piston according to the present invention involves multi functionality or being a "multi dimensional piston" by: (a) handling the combustion and power stroke, (b) serving as an inlet valve, (c) serving in the exhaust process, the piston may be regarded as being a "3D" piston.

[0093] In addition, since the piston **30** moves linearly along the longitudinal axis **A**, and, since the pressure applied on the piston **30** by the piston rod **34** is directed continuously along the same line, there are no side forces acting on the piston like in conventional engines where a base of the piston rod rotates around the crankshaft thereby applying alternating side forces on the piston, and, therefore, the piston according to the present invention may be regarded as a "traverse stressless action piston". Thus, due to the lack of sideways mechanical stresses, the need of an oiling system is avoided. This feature may also reduce the accumulated heat during the process and may reduce the need to supply cooling.

[0094] Thus, as acting along a single linear line and having the piston rod serving as an exhaust valve running inside the engine, i.e., an internal exhaust valve or "sliding valve", the engine according to the present invention may be regarded as an "internal combustion engine, with a linear 3D piston, self-scavenged and cooled, direct low pressure fuel injection system, aligned piston movement, and a running sliding valve.

[0095] Although the present invention has been described to a certain degree of particularity, it should be understood that various alterations and modifications could be made without departing from the spirit or scope of the invention as hereinafter claimed.

[0096] For example, the engine is not limited to have only one cylinder and it may have two or more cylinders.

[0097] The exhaust openings do not have to be equally peripherally distributed around the piston rod and they may be arranged in a different array according to design needs.

[0098] The cavity of the piston rod do not have to extend along the entire length of the piston rod. Preferably, the cavity extends at least from an open end of the piston rod, which is remote from the piston, to the exhaust opening that is closest to the piston.

[0099] The exhaust openings in the piston rod do not have to be formed as described. According to some embodiments, the piston rod is not formed with exhaust openings or with a cavity passing along the length of the piston rod. Alternatively, as shown in Fig. 19, the piston rod **34** is a solid rod and is provided on the surface thereof with longitudinally extending grooves **91**. Since the piston **30**, with the piston rods **34**, move longitudinally along the cylinder inner space, the longitudinally extending grooves **91** are exposed, as required, to the cylinder inner space or to the exhaust chamber, thus performing the exhaust action.

[0100] The cooling fins do not have to be constructed as shown, i.e., have a disc-like shape or a square shape, and any other shape of cooling fins may be chosen according to construction and design needs.

[0101] The piston may be solid, without a through bore, as described above, where each of the piston rods is, independently or otherwise, connected to its side of the piston. Alternatively, the piston may be provided with a through bore

in order to connect therethrough each of the piston rods to each other. However, it should be clarified that no gases may flow from one side of the piston to another side of the piston through the piston rods.

[0102] The unique design of the central air feed filling the cylinder with pre-charged fresh air allows to apply traditional valves, one or more on each side of the cylinder head. The valves are closed by a spring and are opened by a mechanical mechanism. Alternatively, they may be electrically operated. The valves can open immediately after the work stroke ends its efficient move and remain open until the piston moves to the opposite end and back to direction of compression stroke. At the same time, the air entering the cylinder fills the increased volume of the cylinder as the piston moves to the opposite direction. The use of traditional valves or ports requires to apply small exhaust units at the ends of the engine head to collect and prevent any leaking gases from being escaped to the atmosphere.

[0103] The small exhaust chamber is a self-contained unit or part of the engine head. Hot gases are trapped in the exhaust chamber and are directed to the exhaust manifold for after-treatment.

[0104] Fig. 8 shows a modified version of an engine head 93 when valves are used.

[0105] According to some embodiments (see Fig. 18), the linear movement of two adjacent aligner rods 68, e.g., an upper aligner rod 94 and a lower aligner rod 96 (and hence, the linear movement of the engine 10) is used for producing a rotational movement **R** around an output axis **C**. The upper aligner rod 94 is provided, in a central portion thereof, with an upper rack 98, and the lower aligner rod 96 is provided, in a central portion thereof, with a lower rack 100. The upper rack 98 is facing the lower rack 100 and each of them is engaged with a different pinion. The upper rack 98 is engaged with a first pinion 102 and the lower rack 100 is engaged with a second pinion 104 that is parallel to the first pinion 102 and separated therefrom.

[0106] The first pinion 102 and the second pinion 104 are assembled on a common axis, i.e., the output axis **C**. Each of the pinions is provided with a uni-directional bearing, being a mechanical or electrical bearing. In the embodiment shown, the first pinion 102 rotates anticlockwise when the upper aligner rod 94 moves to the left side, and remains idle when the upper aligner rod 94 moves to the right side. Likewise, the second pinion 104 rotates anticlockwise when the lower aligner rod 96 moves to the right side, and remains idle when the lower aligner rod 96 moves to the left side.

[0107] Thus, when the piston of the engine 10 linearly moves toward a given direction, together with the aligner rods 68, only one pinion rotates while the other pinion remains idle. When the piston of the engine 10 linearly moves toward the opposite direction, together with the aligner rods 68, the other pinion rotates. Thus, by alternately rotated by the aligner rods, each pinion by a different direction of the aligner rods, the pinions rotate the mutual output axis **C** in a single direction only (being anticlockwise, as arbitrary shown in Fig. 17, or, at the opposite direction, i.e., clockwise). Therefore, the engine of the present invention may be used for producing a rotational movement for any known mechanical application, e.g., a propeller 106 of an aircraft, an electric producing generator, and the like. Furthermore, the engine of the present invention may be used for compressing liquids or gases.

[0108] The rotational movement **R** is established substantially around the output axis **C** that is perpendicular to the longitudinal axis **A** of the engine 10.

[0109] The engine is not limited to use fuel that is ignited by means of a spark plug, and, if required, the engine may use diesel self-igniting fuel. In that case, the spark plug is omitted from the engine.

[0110] In some embodiments, in order to prevent burned gas leakage the engine comprises a transient chamber that is connected to the exhaust manifold.

[0111] In some embodiments, the exhaust openings are near the inlet openings.

Claims

1. An internal combustion engine (10) for generating a linear reciprocating movement of an output shaft along a longitudinal axis (A), the engine comprising:

a double sided cylinder (12), the cylinder bounded by an engine head (26) at each side thereof, wherein the cylinder comprises inlet openings (14);

an exhaust unit (48) positioned at each end of the cylinder; wherein the engine further comprises:

a double sided piston (30) positioned within a cylinder inner space (32) and sliding with respect to the cylinder along the longitudinal axis;

two piston rods (34) aligned with the longitudinal axis, each piston rod connected at an opposite side of the piston, **characterised in that:**

each of the piston rods comprises exhaust openings (38, 56, 91);

each of the piston rods is provided with a cavity (36) for gas to flow through the piston rods, the cavity extending at least from an end of the piston rod, which is remote from the piston, to an exhaust opening,

the exhaust opening being closer to the piston than the end, with no interconnecting flow passage from the cavity of one piston rod to that of the other piston rod.

2. The engine (10) according to claim 1, wherein:

the exhaust openings constitute exhaust valves that form an integral part of the piston rods; or wherein each of the piston rods constitutes a sliding valve.

3. The engine (10) according to claim 1, wherein:

the piston constitutes an inlet valve and an exhaust valve; or wherein the piston is symmetrical with respect to a median plane (P) thereof.

4. The engine (10) according to claim 1, wherein:

the engine operates through an Aquarius cycle, the Aquarius cycle comprising the steps of:
(a) work, (b) exhaust, (c) scavenging, (d) gas boost, (e) compression.

5. The engine (10) according to claim 1, wherein:

the exhaust openings comprise at least one from the group of: holes, longitudinal slots, and grooves; and the exhaust openings are arranged in one group or a multitude of groups.

6. The engine (10) according to claim 1, wherein:

the cylinder (12) comprises the inlet openings (14) at a central portion (16) thereof.

7. The engine (10) according to claim 1, wherein:

the cylinder comprises a continuous flow of pre-charged air therethrough, optionally wherein the cylinder comprises a cylinder wall (33) at an inner portion thereof, and, the continuous flow of air scavenges the cylinder from burned gases, cools the cylinder wall and the piston, and enriches the burned gases without depending on the position of the piston.

8. The engine (10) according to claim 1, wherein:

the burned gases exhaust the cylinder through the piston rod.

9. The engine (10) according to claim 1, wherein:

the burned gases exit the cylinder at the end of an efficient work stroke.

10. The engine (10) according to claim 1, wherein:

the piston constitutes a multifunctional piston or a traverse stressless action piston.

11. The engine (10) according to claim 1, wherein:

the engine comprises a transient chamber connected to the exhaust manifold for prevention of burned gas leakage.

12. The engine (10) according to claim 1, further comprising:

an aligner system (60) for preventing rotation of the piston around the longitudinal axis (A),
wherein:

the aligner system comprises aligner rods (68) that are directed parallel to the longitudinal axis and are connected to the piston rod through connecting arms (64);

the aligner rods comprise coil winding (84); and

the engine further comprises an electric motor (88) that generates electric power by means of stator coils (90) that are energized by a linear back and forth movement of the aligner rods therethrough.

13. The engine (10) according to claim 1, further comprising:

an aligner system (60) for preventing rotation of the piston around the longitudinal axis (A),
wherein:

the aligner system comprises aligner rods (68) that are directed parallel to the longitudinal axis and are connected to the piston rod through connecting arms (64), and the engine further comprises a system for transforming

linear movement to rotational movement; and
the system comprises:

- 5 a first pinion (102) rotated by a first rack (98) that is connected to a first aligner rod (94), the first pinion is rotated to a single direction (R);
a second pinion (104) rotated by a second rack (100) that is connected to a second aligner rod (96) that is adjacent the first aligner rod, the second pinion is rotated to a single direction that is the same as the rotation direction (R) of the first pinion; and wherein
- 10 the first pinion and the second pinion are aligned and rotate around an output axis (C).

Patentansprüche

- 15 1. Verbrennungsmotor (10) zum Erzeugen einer linearen hin- und hergehenden Bewegung einer Abtriebswelle entlang einer Längsachse (A), wobei der Motor aufweist:
- einen doppelseitigen Zylinder (12), wobei der Zylinder durch einen Motorkopf (26) an jeder Seite davon begrenzt ist, wobei der Zylinder Einlassöffnungen (14) aufweist;
- 20 wobei eine Auspuffeinheit (48) an jedem Ende des Zylinders angeordnet ist, wobei der Motor ferner aufweist:
- einen doppelseitigen Kolben (30), der innerhalb eines Zylinderinnenraums (32) angeordnet ist und in Bezug auf den Zylinder entlang der Längsachse gleitet;
- 25 zwei Kolbenstangen (34), die mit der Längsachse ausgerichtet sind, wobei jede Kolbenstange an einer entgegengesetzten Seite des Kolbens verbunden ist;
- dadurch gekennzeichnet, dass**
- jede der Kolbenstangen Auslassöffnungen (38, 56, 91) aufweist;
- jede der Kolbenstangen einen Hohlraum (36) aufweist, so dass Gas durch die Kolbenstangen strömen kann, wobei sich der Hohlraum mindestens von einem Ende der Kolbenstange, das vom Kolben entfernt ist, bis zu einer Auslassöffnung erstreckt, wobei die Auslassöffnung näher am Kolben angeordnet ist als das Ende, ohne dass ein verbindender Strömungsdurchgang vom Hohlraum einer Kolbenstange zu demjenigen der anderen Kolbenstange vorhanden ist.
- 30
- 35 2. Motor (10) nach Anspruch 1, wobei
- die Auslassöffnungen Auslassventile bilden, die einen integralen Bestandteil der Kolbenstangen bilden, oder wobei jede der Kolbenstangen ein Gleitventil bildet.
- 40 3. Motor (10) nach Anspruch 1, wobei
- der Kolben ein Einlassventil und ein Auslassventil bildet, oder
- wobei der Kolben in Bezug auf eine Mittelebene (P) davon symmetrisch ist.
- 45 4. Motor (10) nach Anspruch 1, wobei
- der Motor einen Aquarius-Zyklus durchläuft, wobei der Aquarius-Zyklus die Schritte aufweist: (a) Arbeiten, (b) Auspuffen, (c) Spülen, (d) Gas-Boost, (e) Verdichten.
- 50 5. Motor (10) nach Anspruch 1, wobei:
- die Auslassöffnungen mindestens eine Öffnung aus der Gruppe Löcher, Längsschlitze und Nuten aufweisen, und die Auslassöffnungen in einer Gruppe oder einer Vielzahl von Gruppen angeordnet sind.
6. Motor (10) nach Anspruch 1, wobei
- 55 der Zylinder (12) die Einlassöffnungen (14) an einem Mittenabschnitt (16) davon aufweist.
7. Motor (10) nach Anspruch 1, wobei

der Zylinder eine kontinuierliche Strömung von Vorladeluft durch ihn hindurch aufweist, wobei der Zylinder optional eine Zylinderwand (33) an einem inneren Abschnitt davon aufweist und die kontinuierliche Luftströmung den Zylinder von verbrannten Gasen spült, die Zylinderwand und den Kolben kühlt und die verbrannten Gase anreichert, unabhängig von der Position des Kolbens.

8. Motor (10) nach Anspruch 1, wobei die verbrannten Gase über die Kolbenstange aus dem Zylinder ausgestoßen werden.
9. Motor (10) nach Anspruch 1, wobei die verbrannten Gase am Ende eines effizienten Arbeitstaktes aus dem Zylinder austreten.
10. Motor (10) nach Anspruch 1, wobei der Kolben ein Multifunktionskolben oder ein belastungsfrei arbeitender Vorschubkolben ist.
11. Motor (10) nach Anspruch 1, wobei der Motor eine mit dem Auspuffkrümmer verbundene Übergangskammer zum Verhindern von Leckagen verbrannter Gase aufweist.
12. Motor (10) nach Anspruch 1, ferner mit einem Ausrichtungssystem (60) zum Verhindern einer Drehbewegung des Kolbens um die Längsachse (A), wobei das Ausrichtungssystem Ausrichtungstangen (68) aufweist, die parallel zur Längsachse ausgerichtet und über Verbindungsarme (64) mit der Kolbenstange verbunden sind, die Ausrichtungstangen eine Spulenwicklung (84) aufweisen, und der Motor ferner einen Elektromotor (88) aufweist, der mittels Statorspulen (90), die durch eine lineare hin- und hergehende Bewegung der Ausrichtungstangen durch sie hindurch erregt werden, elektrische Energie erzeugt.
13. Motor (10) nach Anspruch 1, ferner mit:
einem Ausrichtungssystem (60) zum Verhindern einer Drehbewegung des Kolbens um die Längsachse (A), wobei das Ausrichtungssystem Ausrichtungstangen (68) aufweist, die parallel zur Längsachse ausgerichtet und über Verbindungsarme (64) mit der Kolbenstange verbunden sind, und der Motor ferner ein System zum Umwandeln einer linearen Bewegung in eine Drehbewegung aufweist, und das System aufweist:
ein erstes Ritzel (102), das durch eine erste Zahnstange (98) gedreht wird, die mit einer ersten Ausrichtungstange (94) verbunden ist, wobei das erste Ritzel in eine einzige Richtung (R) gedreht wird;
ein zweites Ritzel (104), das durch eine zweite Zahnstange (100) gedreht wird, die mit einer zweiten Ausrichtungstange (96) verbunden ist, die der ersten Ausrichtungstange benachbart ist, wobei das zweite Ritzel in eine einzige Richtung gedreht wird, die der Drehrichtung (R) des ersten Ritzels gleicht, und wobei das erste Ritzel und das zweite Ritzel miteinander ausgerichtet sind und sich um eine Ausgangsachse (C) drehen.

Revendications

1. Moteur de combustion interne (10) pour la génération d'un mouvement alternatif linéaire d'un arbre de sortie le long d'un axe longitudinal (A), le moteur comprenant :
un cylindre à deux côtés (12), le cylindre étant limité par une culasse de moteur (26) de chaque côté de celui-ci, dans lequel le cylindre comprend des ouvertures d'admission (14) ;
une unité d'échappement (48) positionnée à chaque extrémité du cylindre ; dans lequel le moteur comprend en outre :
un piston à deux côtés (30) positionné à l'intérieur d'un espace interne (32) du cylindre et coulissant par rapport au cylindre le long de l'axe longitudinal ;

deux tiges de piston (34) alignées avec l'axe longitudinal, chaque tige de piston étant reliée à un côté opposé du piston, **caractérisé en ce que** :

chacune des tiges de piston comprend des ouvertures d'échappement (38, 56, 91) ;
chacune des tiges de piston est pourvue d'une cavité (36) pour que le gaz s'écoule à travers les tiges de piston, la cavité s'étendant au moins à partir d'une extrémité de la tige de piston, qui est éloignée du piston, jusqu'à une ouverture d'échappement, l'ouverture d'échappement étant plus proche du piston que l'extrémité, sans passage de débit d'interconnexion depuis la cavité d'une tige de piston vers celle de l'autre tige de piston.

2. Moteur (10) selon la revendication 1, dans lequel :
les ouvertures d'échappement constituent des soupapes d'échappement qui sont partie intégrante des tiges de piston ; ou dans lequel chacune des tiges de piston constitue une soupape coulissante.

3. Moteur (10) selon la revendication 1, dans lequel :
le piston constitue une soupape d'admission et une soupape d'échappement ; ou dans lequel le piston est symétrique par rapport à un plan médian (P) de celui-ci.

4. Moteur (10) selon la revendication 1, dans lequel :
le moteur fonctionne selon un cycle d'Aquarius, le cycle d'Aquarius comprenant les étapes de :
(a) travail, (b) échappement, (c) récupération, (d) surcroît de gaz, (e) compression.

5. Moteur (10) selon la revendication 1, dans lequel :

les ouvertures d'échappement comprennent au moins un élément du groupe constitué par : les orifices, les fentes longitudinales et les rainures ; et
les ouvertures d'échappement sont disposées dans un groupe ou une multitude de groupes.

6. Moteur (10) selon la revendication 1, dans lequel :
le cylindre (12) comprend les ouvertures d'entrée (14) au niveau d'une partie centrale (16) de celui-ci.

7. Moteur (10) selon la revendication 1, dans lequel :
le cylindre comprend un débit continu d'air préchargé à travers celui-ci, éventuellement dans lequel le cylindre comprend une paroi de cylindre (33) au niveau d'une partie interne de celui-ci, et le débit continu d'air récupère les gaz brûlés du cylindre, refroidit la paroi du cylindre et le piston, et enrichit les gaz brûlés indépendamment de la position du piston.

8. Moteur (10) selon la revendication 1, dans lequel :
les gaz brûlés s'échappent du cylindre à travers la tige de piston.

9. Moteur (10) selon la revendication 1, dans lequel :
les gaz brûlés quittent le cylindre à la fin d'une course de travail efficace.

10. Moteur (10) selon la revendication 1, dans lequel :
le piston constitue un piston multifonctionnel ou un piston à action sans contrainte transversale.

11. Moteur (10) selon la revendication 1, dans lequel :
le moteur comprend une chambre transitoire reliée au collecteur d'échappement pour la prévention des fuites de gaz brûlés.

12. Moteur (10) selon la revendication 1, comprenant en outre :

un système d'alignement (60) pour la prévention de la rotation du piston autour de l'axe longitudinal (A), dans lequel :

le système d'alignement comprend des tiges d'alignement (68) qui sont dirigées de manière parallèle à l'axe longitudinal et sont reliées à la tige de piston au travers de bras de liaison (64) ;
les tiges d'alignement comprennent un enroulement de bobine (84) ; et

EP 3 137 754 B1

le moteur comprend en outre un moteur électrique (88) qui génère de la puissance électrique par le biais de bobines de stator (90) qui sont alimentées en énergie par un mouvement de va-et-vient linéaire des tiges d'alignement à travers celles-ci.

5 **13.** Moteur (10) selon la revendication 1, comprenant en outre :

un système d'alignement (60) pour la prévention de la rotation du piston autour de l'axe longitudinal (A), dans lequel :

10 le système d'alignement comprend des tiges d'alignement (68) qui sont dirigées de manière parallèle à l'axe longitudinal et sont reliées à la tige de piston au travers de bras de liaison (64), et le moteur comprend en outre un système destiné à transformer le mouvement linéaire en mouvement de rotation ; et le système comprend :

15 un premier pignon (102) tourné par une première crémaillère (98) qui est reliée à une première tige d'alignement (94), le premier pignon est tourné dans une direction unique (R) ;
un second pignon (104) tourné par une seconde crémaillère (100) qui est reliée à une seconde tige d'alignement (96) qui est adjacente à la première tige d'alignement, le second pignon est tourné dans
20 une direction unique qui est identique à la direction de rotation (R) du premier pignon ; et dans lequel le premier pignon et le second pignon sont alignés et tournent autour d'un axe de sortie (C).

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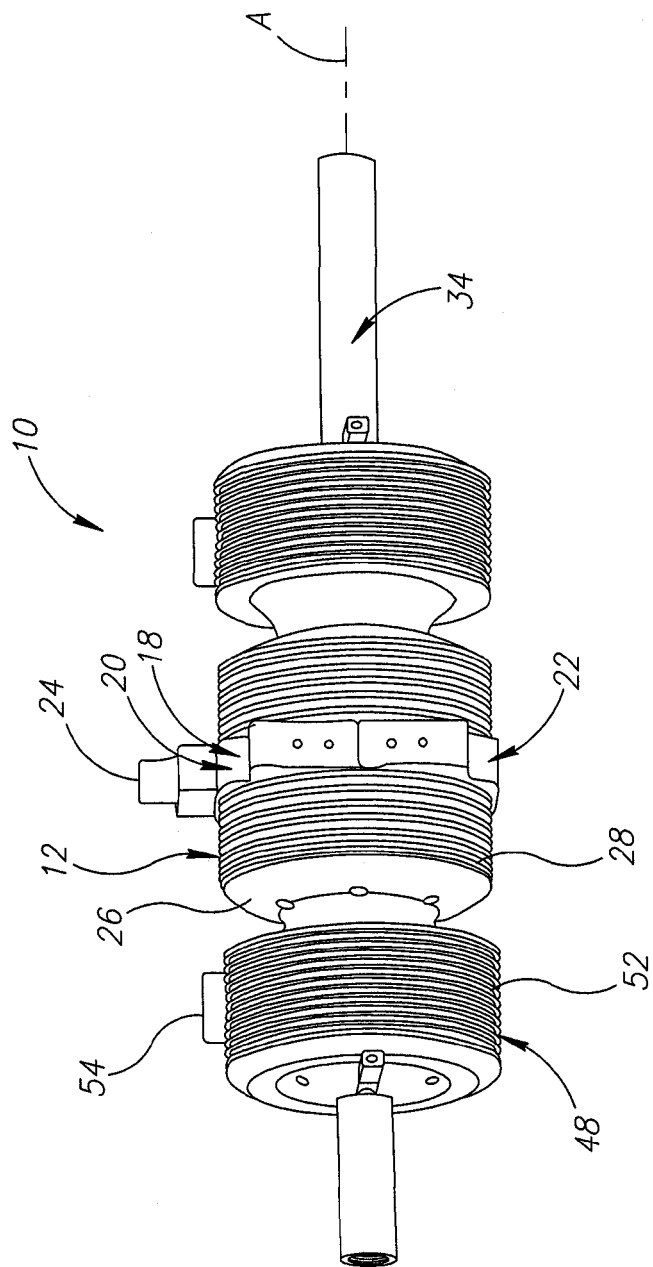


FIG.1

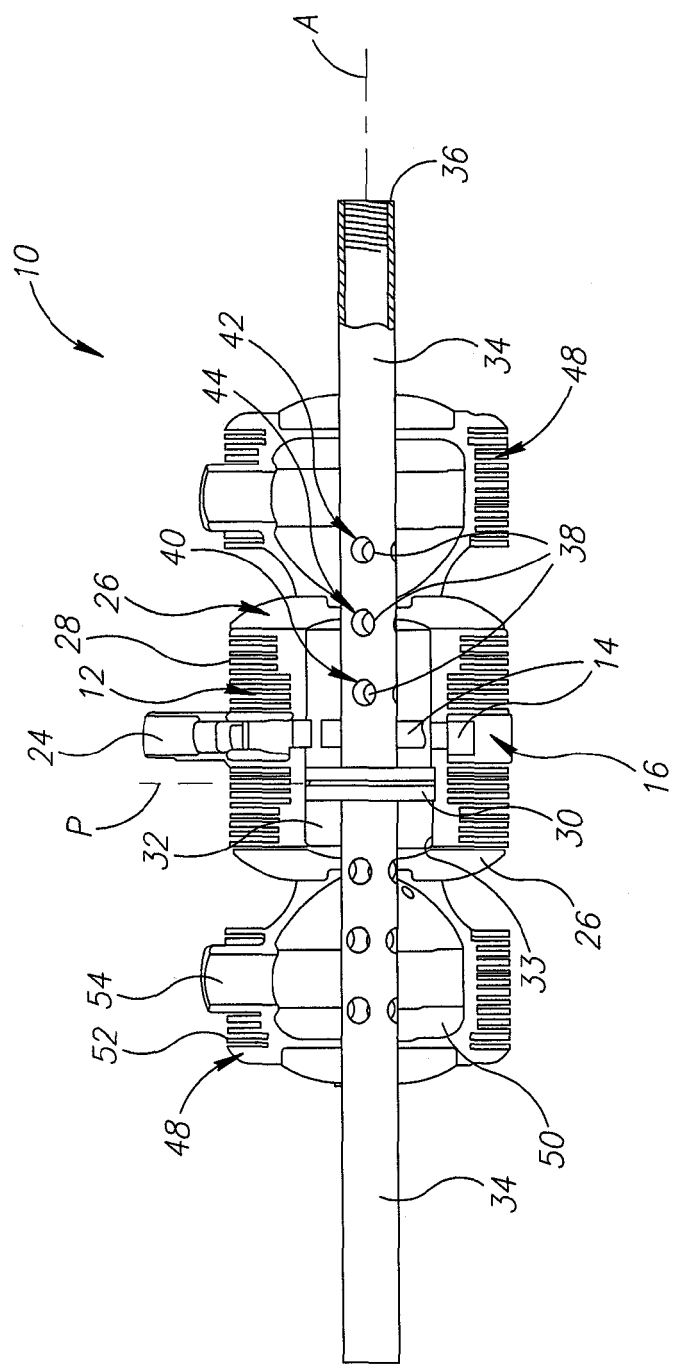


FIG.2

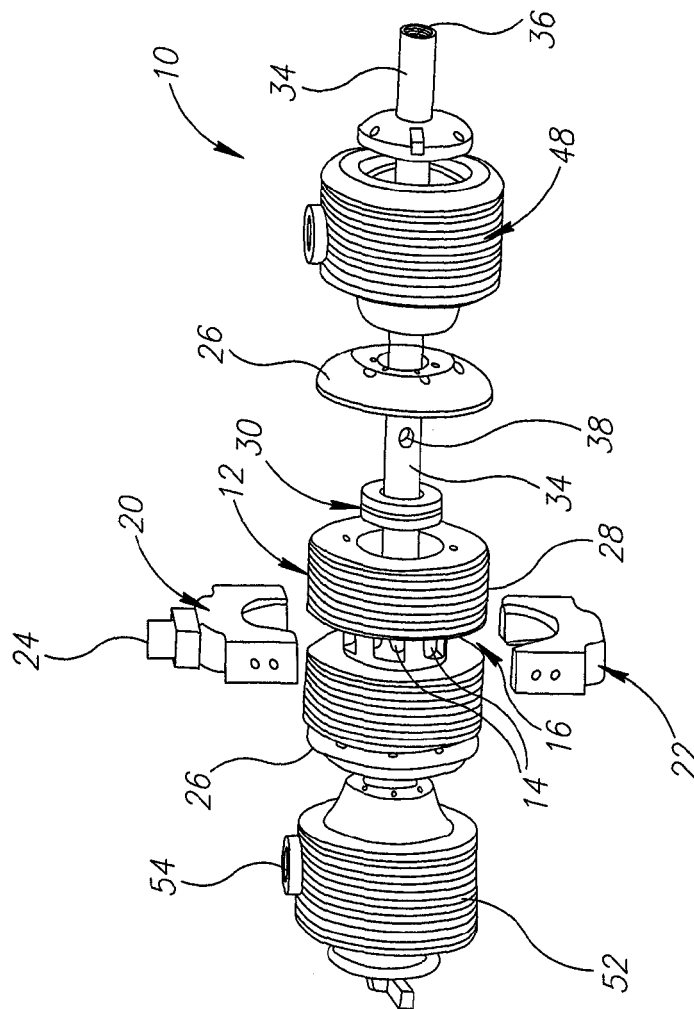


FIG.3

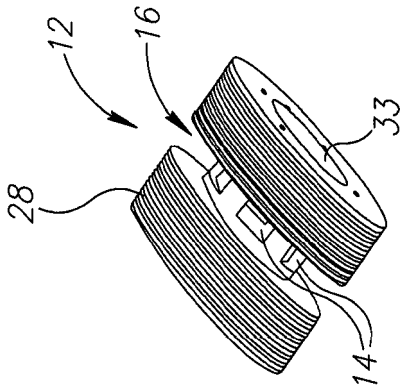


FIG. 5

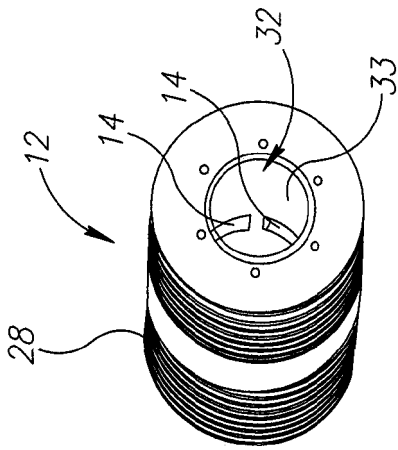


FIG. 4

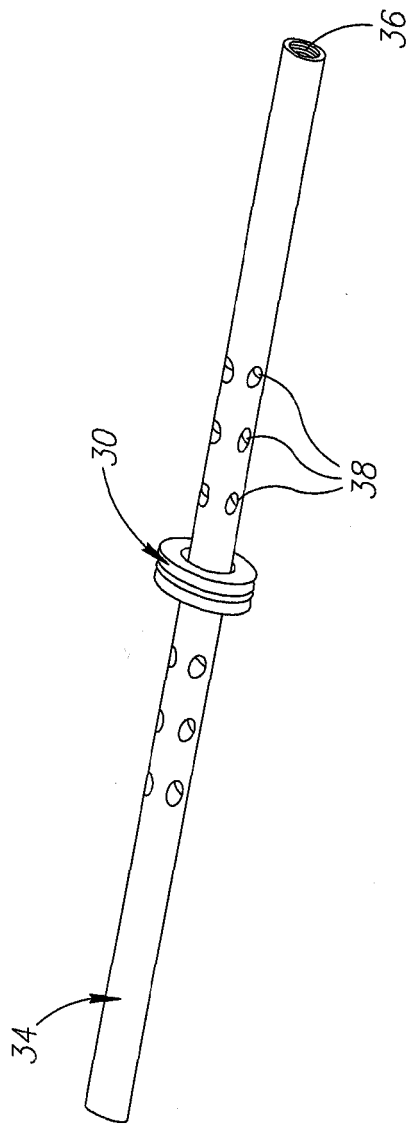


FIG. 6

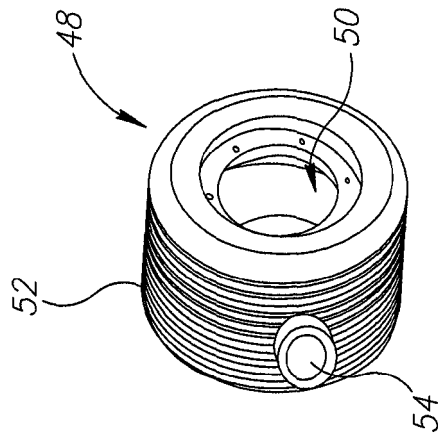


FIG. 7

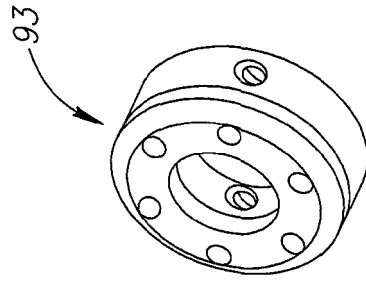


FIG. 8

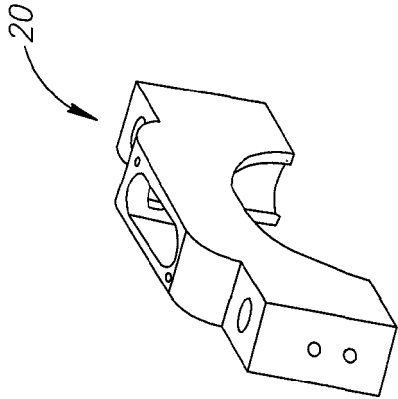


FIG. 9

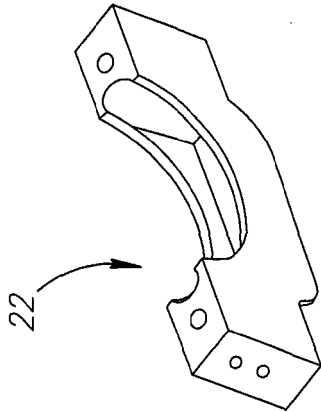


FIG. 10

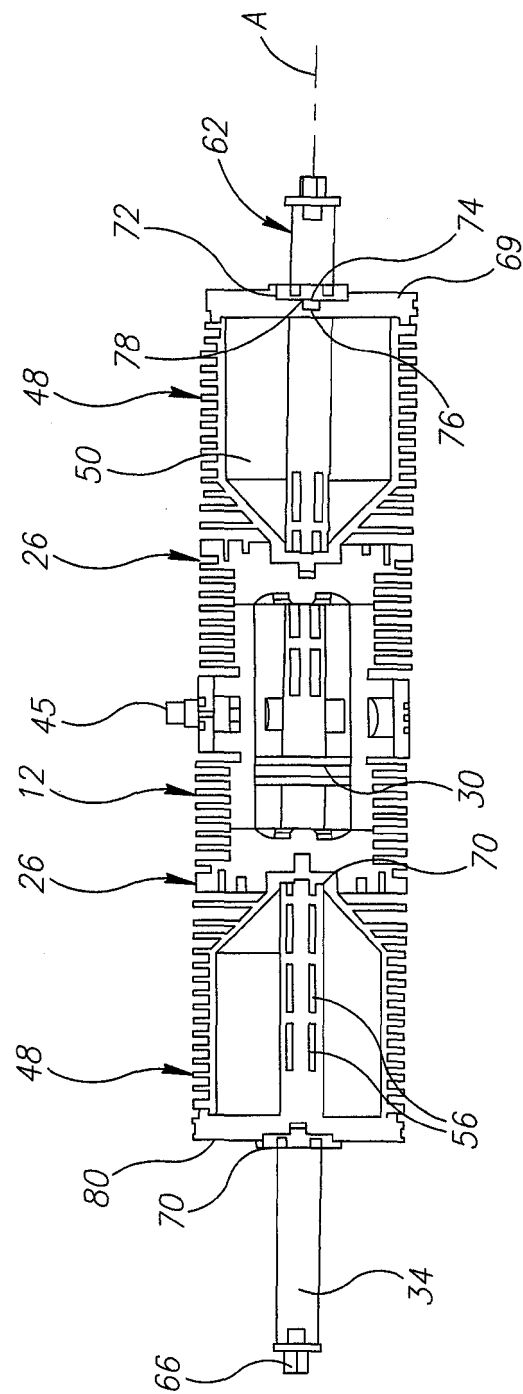


FIG.11

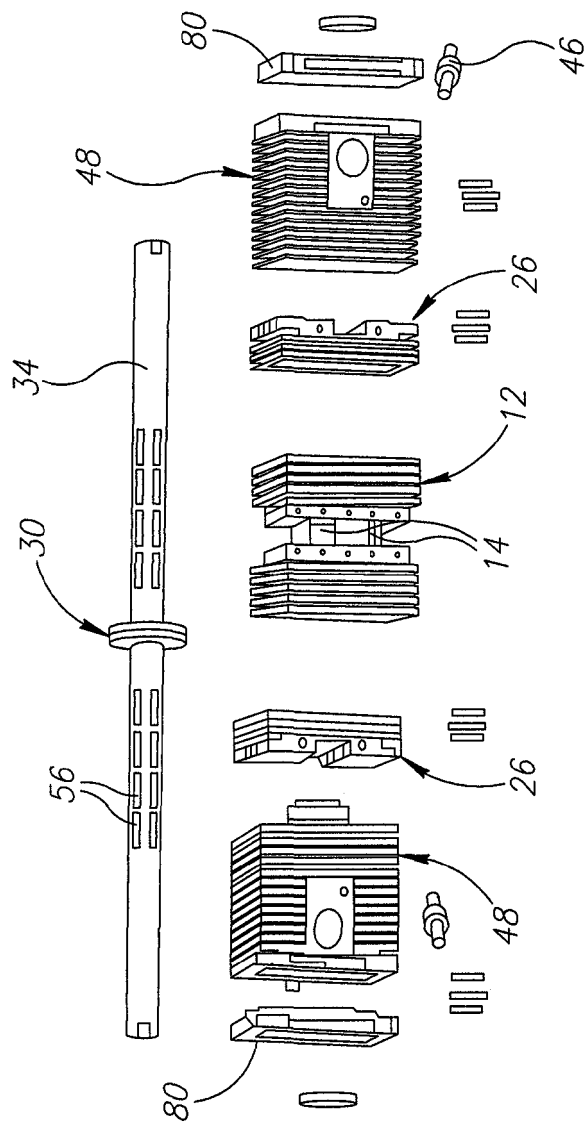


FIG.12

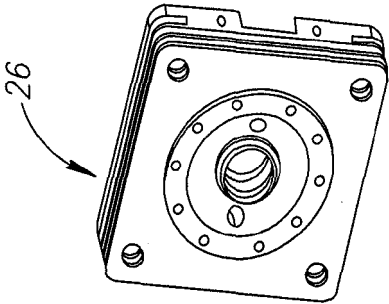


FIG.14

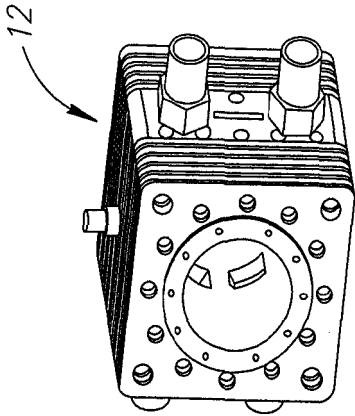


FIG.13

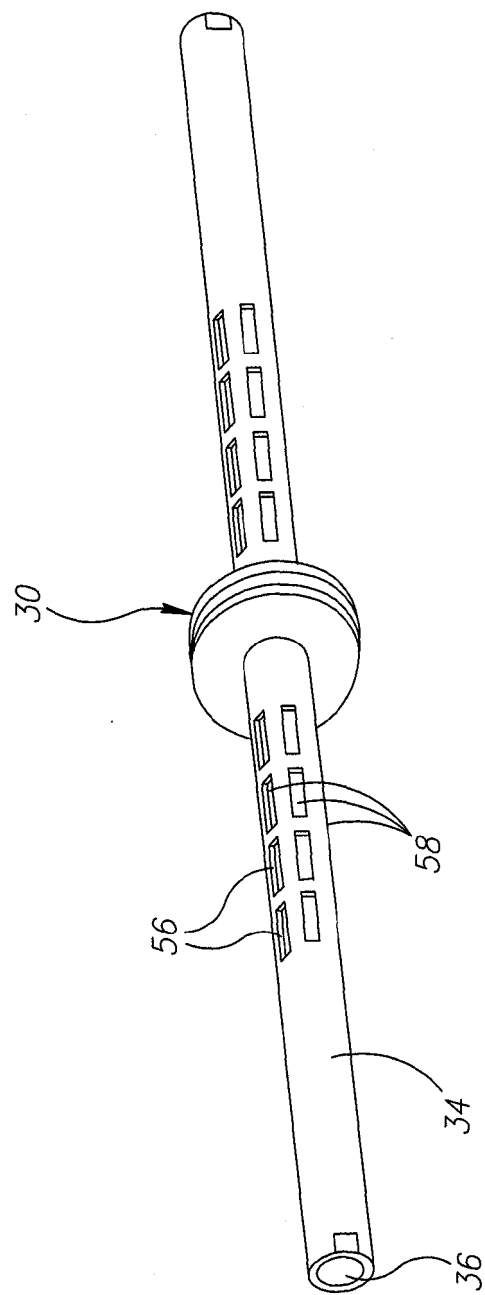


FIG.15

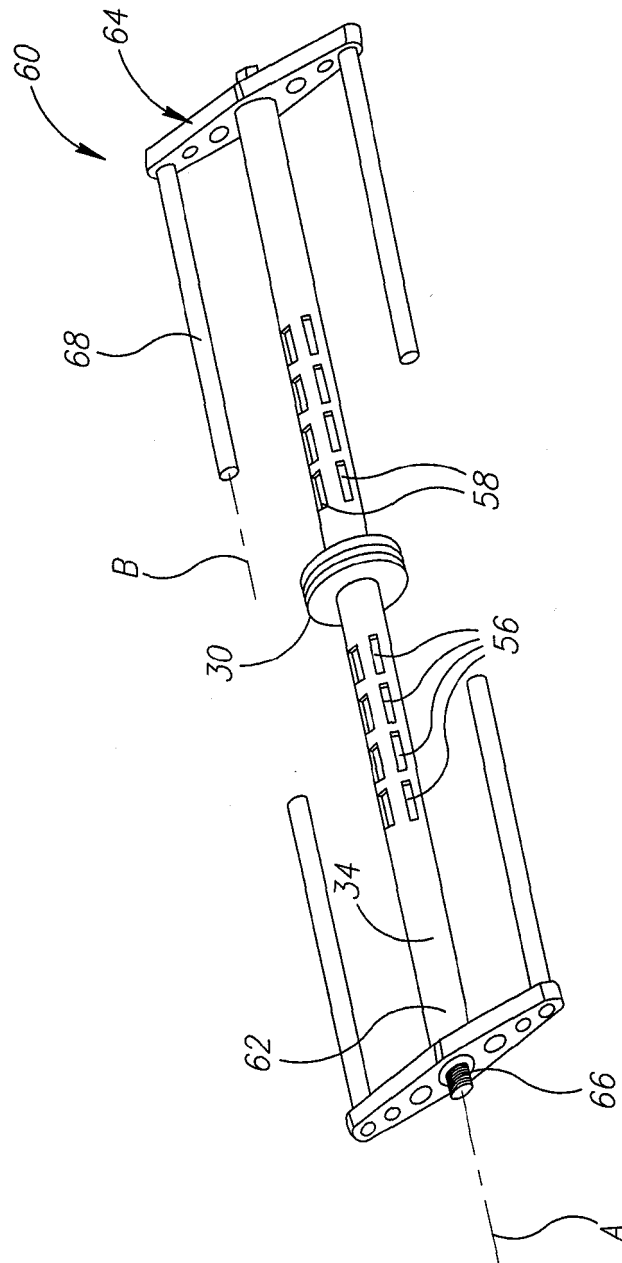


FIG.16

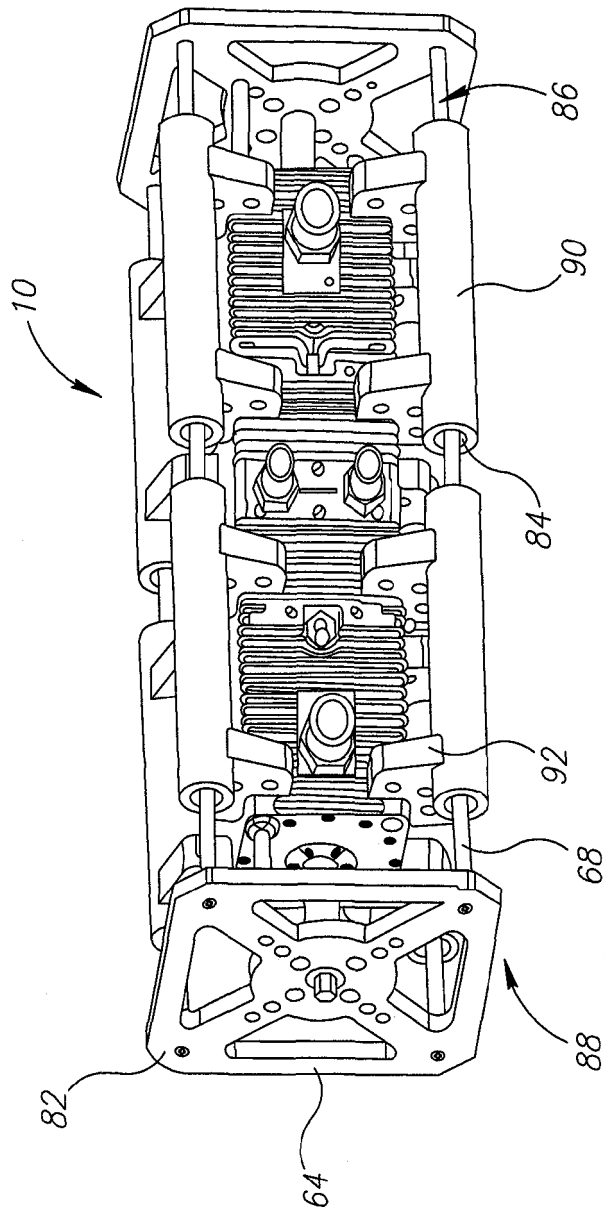


FIG.17

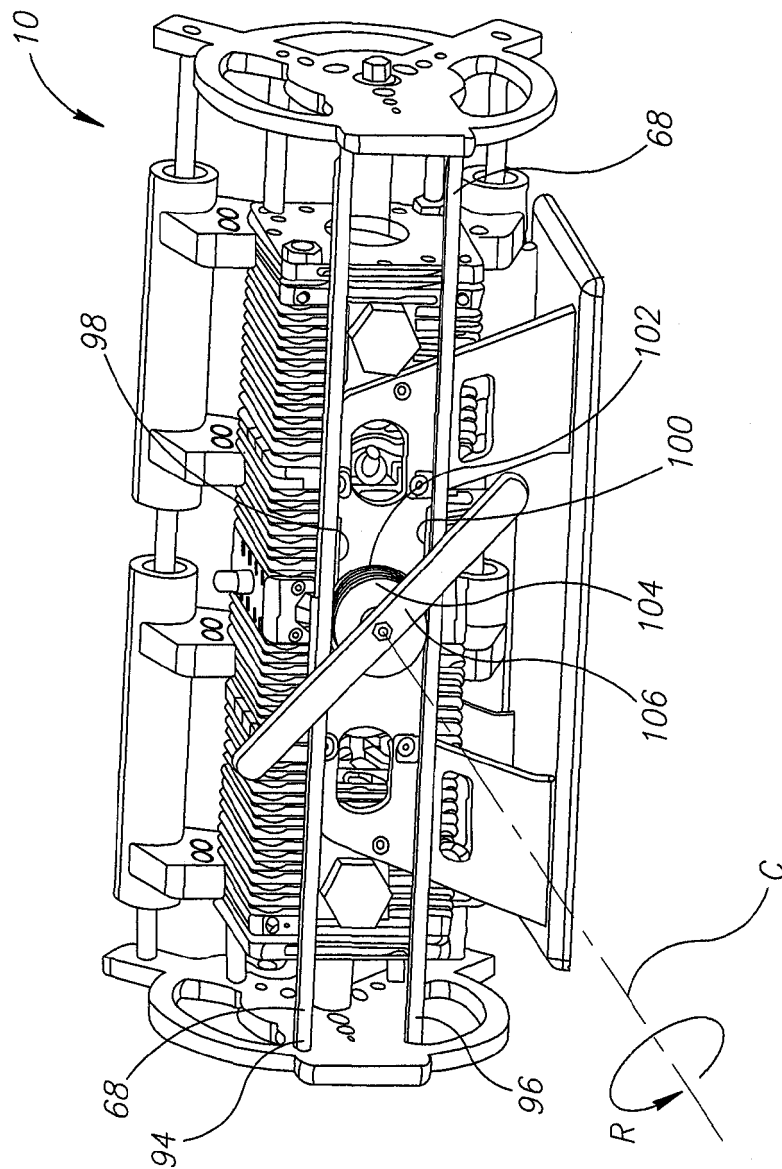


FIG.18

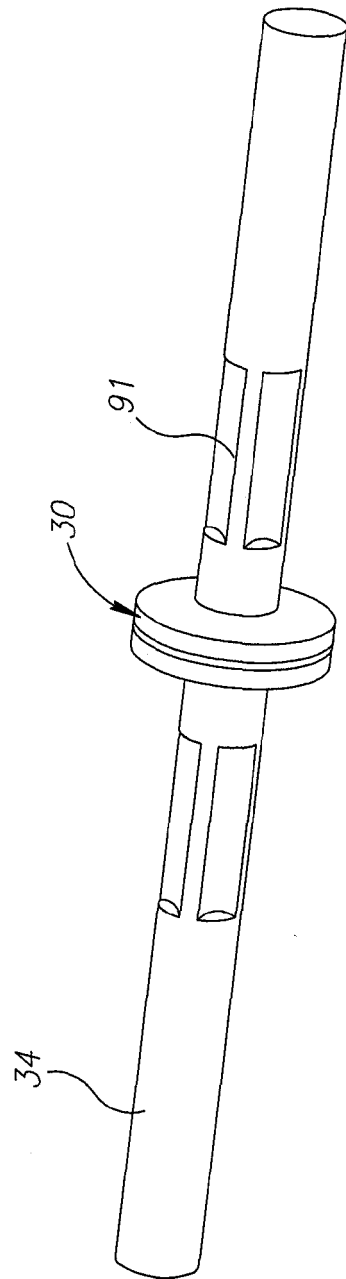


FIG.19

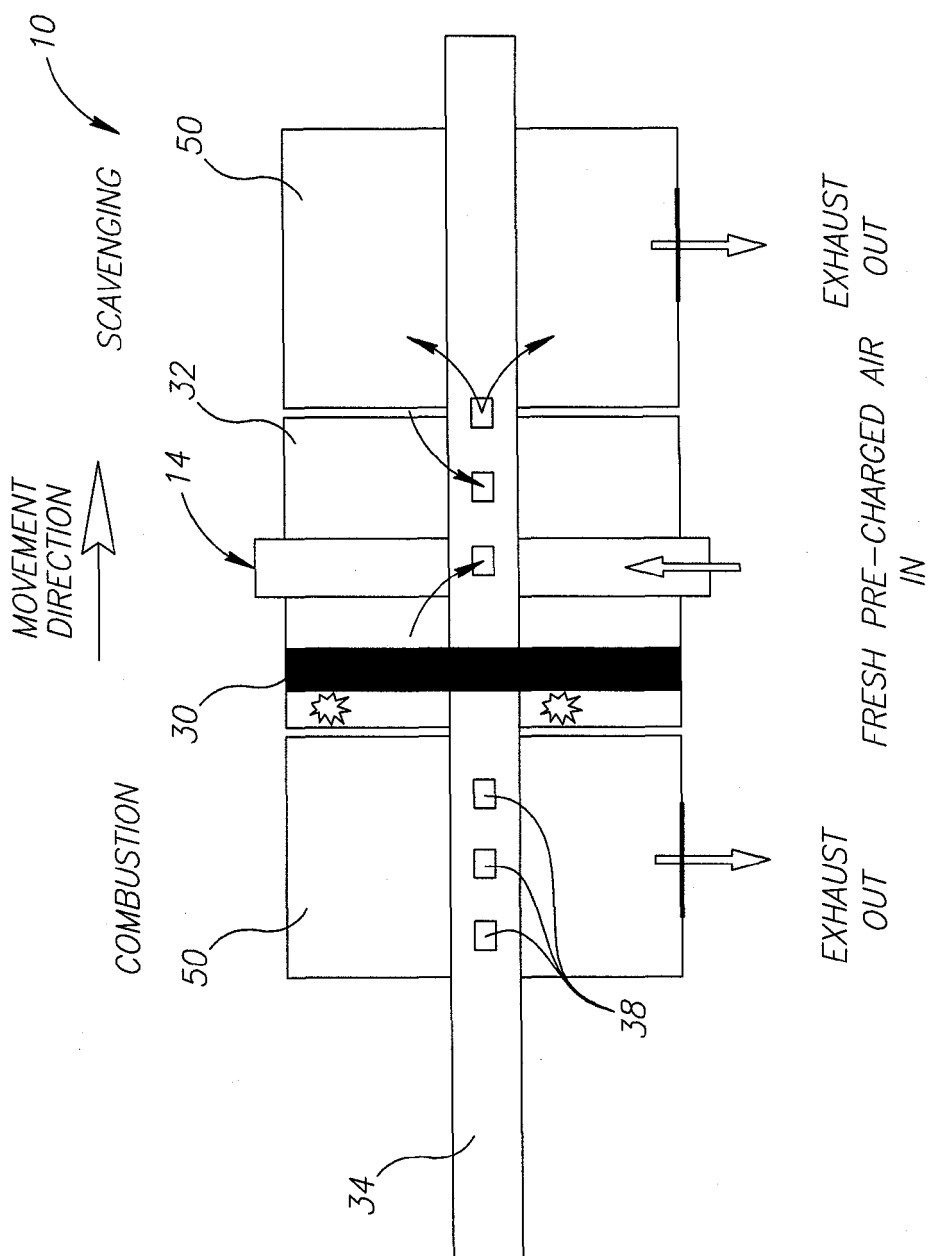


FIG. 20

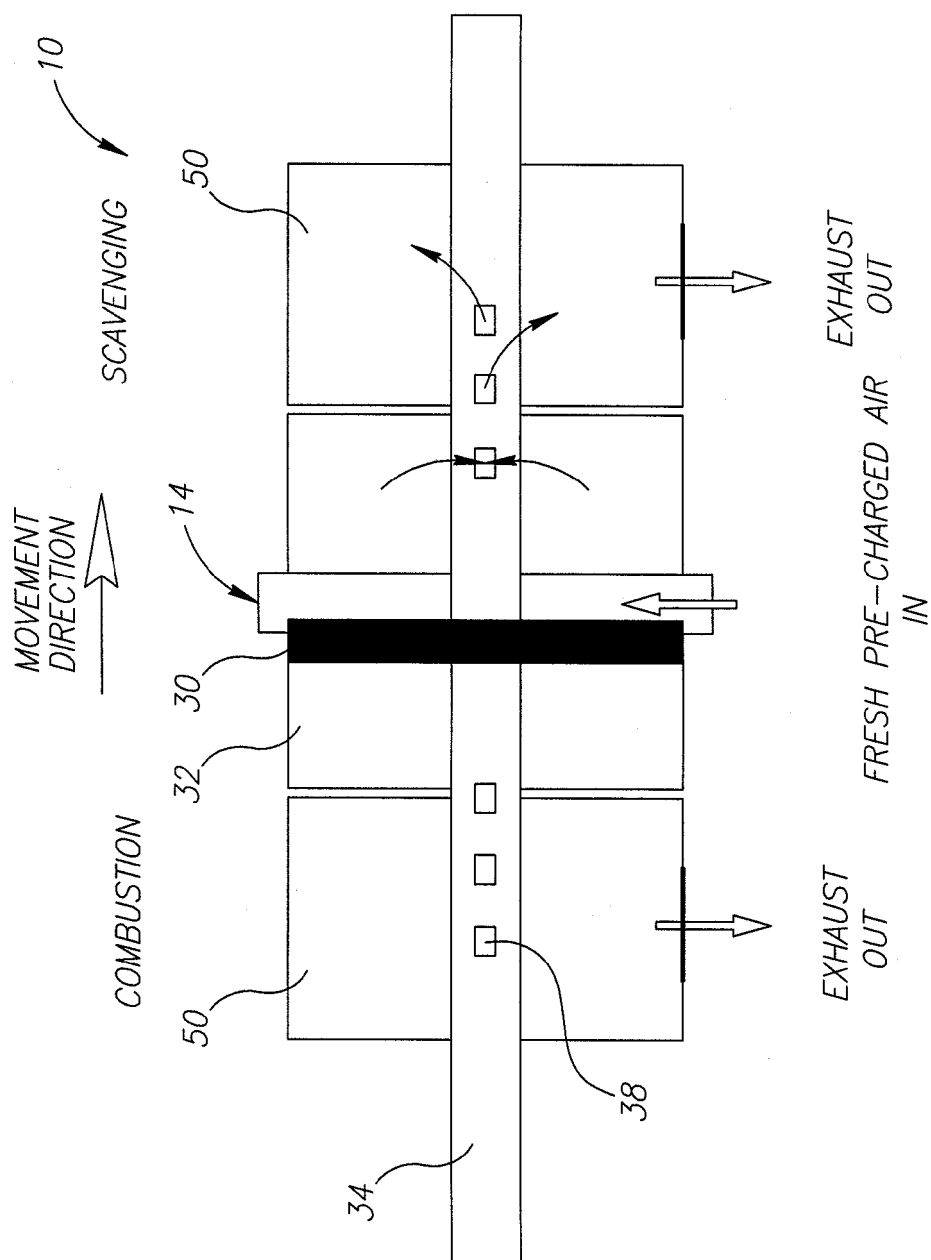


FIG. 21

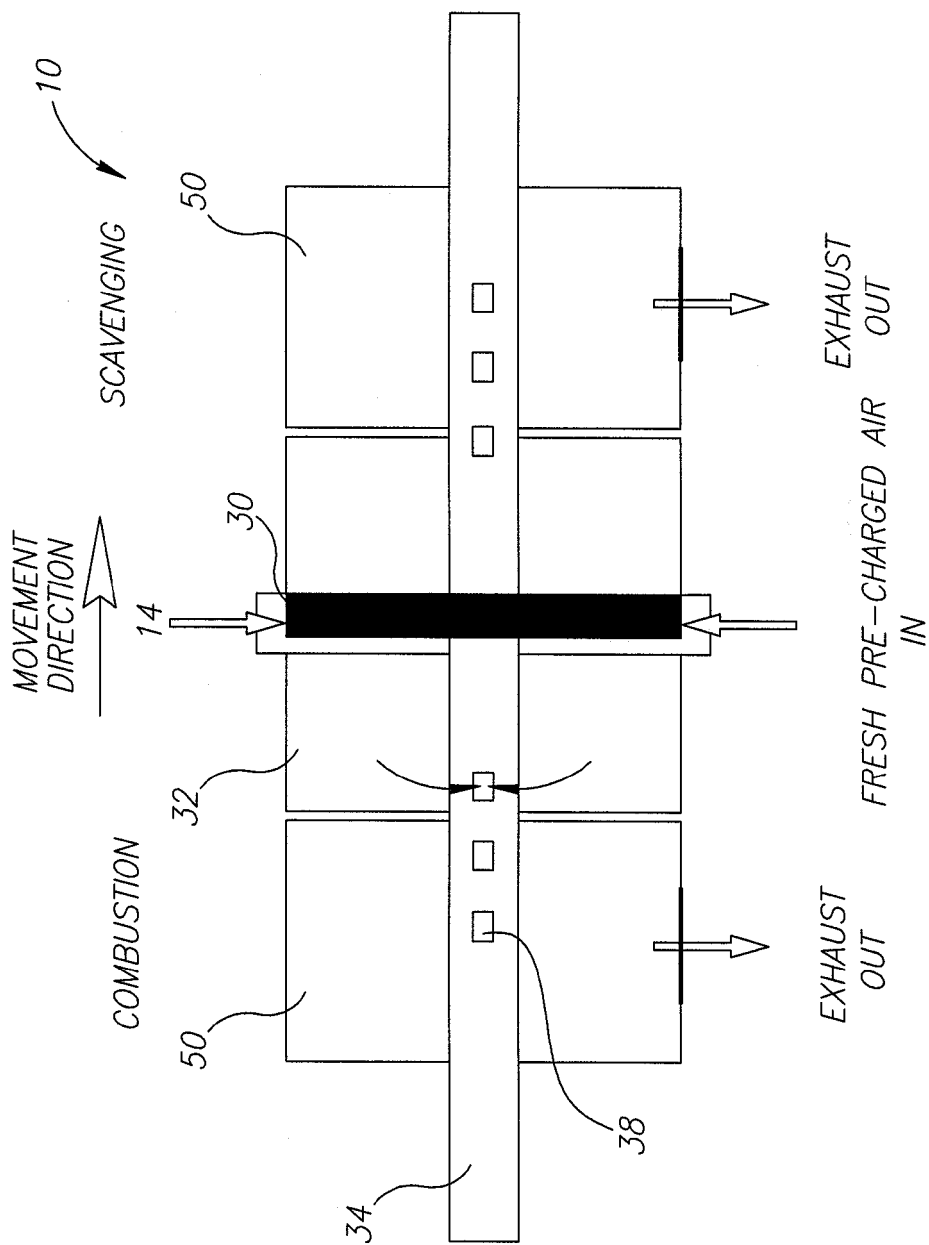


FIG.22

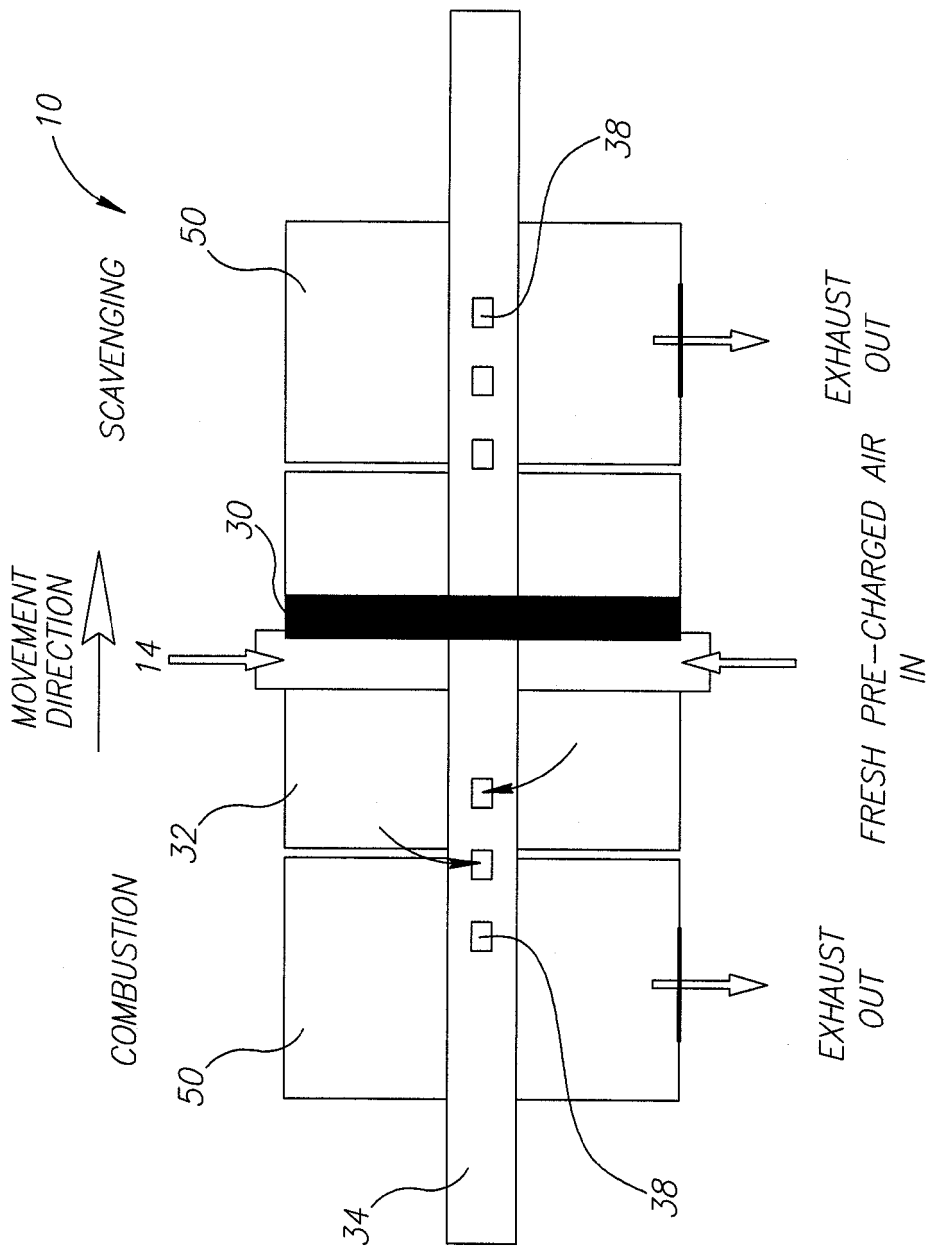


FIG.23

REFERENCES CITED IN THE DESCRIPTION

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